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HYBRID TECHNIQUES FOR COMPLEX AEROSPACE ELECTROMAGNETICS PROBLEMS

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Abstract

Important aerospace electromagnetics problems include the evaluation of antenna performance on aircraft, and the prediction and control of the aircraft's electromagnetic signature. Due to the ever increasing complexity and expense of aircraft design, aerospace engineers have become increasingly dependent on computer solutions. Traditionally, computational electromagnetics (CEM) has relied primarily on four disparate techniques: the method of moments (MoM), the finite-difference time-domain (FDTD) technique, the finite element method (FEM), and high frequency asymptotic techniques (HFAT) such as ray tracing. Each of these techniques has distinct advantages and disadvantages, and no single technique is capable of accurately solving all problems of interest on computers that are available now or will be available in the foreseeable future. As a result, new approaches that overcome the deficiencies of traditional techniques are beginning to attract a great deal of interest in the CEM community. Among these new approaches are hybrid methods which combine two or more of these techniques into a coherent model. During the ASEE Summer Faculty Fellowship Program a hybrid FEM/MoM computer code was developed and applied to a geometry containing features found on many modern aircraft.

INTRODUCTION

The Antenna and Microwave Research Branch (AMRB) at LaRC has identified prediction of the radiation characteristics of antennas on composite aircraft as a research topic of major importance to the aerospace industry over the next decade. Evaluation of these radiation characteristics requires the development of accurate and efficient numerical models. Unfortunately, numerical models based solely on one of the four traditional CEM methods are likely to perform poorly on this task. The problems of interest exhibit a combination of features which include radiation, geometrical complexity, complex materials and large electrical size. While the four traditional CEM techniques (MoM, FDTD, FEM and HFAT) are each well-suited to specific features of these problems, none of these techniques is well-suited to handle all of these features. An overview of the characteristics of the four traditional CEM techniques is given in Table I. Most research to date has focused on using MoM to treat such problems. It has been found that excessive computation times and large matrix condition numbers become troublesome above about 200 MHz. In addition, MoM cannot handle the geometric and material complexity often found in modern aircraft. The other three traditional techniques suffer from their own limitations. However, by combining two or more of these traditional techniques in a coherent hybrid model, wherein each component technique is applied to the part of the problem to which it is best suited, we expect to overcome these limitations. The result would be the development of accurate and efficient simulation tools for these problems.

Previous work on hybrid techniques has concentrated on the combination of MoM and HFAT, and the combination of FEM and MoM. The MoM/HFAT hybrids have enabled workers to model radiating structures on electrically large bodies. However, these methods are limited by the geometrical and material complexity of the structure. The FEM/MoM hybrids have enabled workers to model geometrically and materially complex radiating structures. The limitation of these hybrids is the electrical size of the object, which generally must be less than several tens of wavelengths. In present FEM/MoM hybrids, MoM is used only as a means of treating the radiation property of EM fields in lieu of an absorbing boundary condition (ABC). Research conducted this summer at LaRC has focused on extending FEM/MoM hybrids to problems that feature both complex structures that are well-suited for FEM, and simpler radiating structures that are well suited for MoM. The long term goal of this research is to develop a hybrid FEM/MoM/HFAT technique that can accurately and efficiently solve the problem of complex radiating structures on electrically large structures comprising composite materials.

RESEARCH ACCOMPLISHMENTS

A computer code designed specifically to evaluate the scattering width of the geometry shown in Figure 1 has been implemented. The structure illustrated in Figure 1 includes the following salient features: a geometrically and materially complex cavity region that is well suited for solution via FEM, and simple slot and strip radiators that are well suited for solution via MoM. Such features are common on aircraft. For example, we may be interested in the effect of a nearby jet engine cavity on the radiation pattern of a blade antenna. The insights gained in developing the code for this relatively simple problem will assist researchers in developing similar codes for more complex structures. In addition, many of the specific subroutines developed for this problem, particularly the custom iterative solver, can be directly incorporated into future hybrid codes for more complex problems.

The steps required in the development of the hybrid code for the geometry shown in Figure 1 were development of a MoM solution for the slot and strip radiators, development of an FEM solution for the cavity region, derivation of the system of equations governing the hybrid solution for the geometry, development of a custom iterative solver for this system of equations, and computer implementation of the hybrid solution.

The FEM/MoM hybrid technique requires solution of a linear system comprising a partially sparse, partially dense matrix. The sparse part of the matrix arises from the FEM part of the solution and is, in general, much larger than the dense part of the matrix which results from the MoM part of the solution. Sparse linear systems are well-suited for solution via iterative methods such as the biconjugate gradient algorithm. Significant savings in computation time as well as computer memory can be realized by storing the sparse matrix in profile or banded form and performing operations only on the non-zero elements of the matrix. Unfortunately, such time and memory reduction schemes cannot be used when the matrix is partially dense. For this reason, a custom biconjugate gradient solver has been developed. Use of this custom solver resulted in computation time savings of 100 times or more over dense matrix techniques.

FUTURE RESEARCH

Future research will concentrate on hybridizing the existing FEM/MoM hybrid code with an appropriate HFAT. Incorporation of HFAT into the hybrid code will allow treatment of complex radiating structures on electrically large composite aircraft. Such a hybrid FEM/MoM/HFAT code would be a valuable tool for the aerospace industry.

	TECHNIQUE			
	MoM	FDTD	FEM	HFAT
FEATURE				
Radiation	easy	need ABC	need ABC	easy
Geometrical complexity	hard	easy	easy	impossible
Material complexity	hard	easy	easy	hard
Large electrical size	hard	hard	hard	easy
Non-linearities	impossible	easy	impossible	impossible

Table 1. Overview of CEM methods.

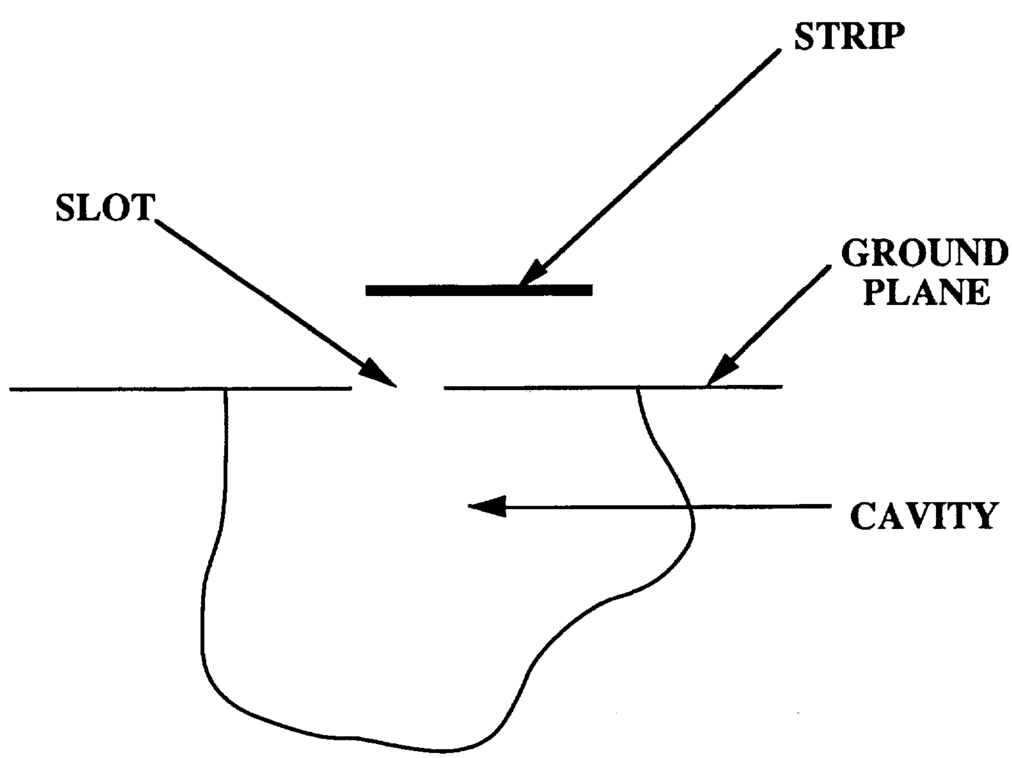

Figure 1. Geometry of strip above a cavity-backed slot.